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FINAL REPORT

1 December 1983 - 30 November 1984

for project

"DEPLOYMENT OF A REGIONAL ARRAY IN NORWAY"

by

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Kjeller, 30 January 1985

Sponsored by
Advanced Research Project Agency (DOD)
ARPA Order No. 4950
Monitored by AFOSR under Contract No. F49620-84-C-0013

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I. SUMMARY

This report gives an account of the work conducted by NORSAR in conjunction with the deployment of a new regional array in Norway under Contract F49620-84-C-0013.

The purpose of the development of an experimental regional array in Norway is to take advantage of the extremely good propagation of high-frequency energy for regional seismic phases in Eurasia. Since Norway is located within the same geologic plate boundary as the Soviet Union, the deployment of such an array in Norway will provide important new insight with respect to the projected performance of possible future in-country stations in the U.S.S.R.

The array has been implemented as a joint undertaking between NORSAR and the Sandia National Laboratories, Albuquerque, NM, USA. The new array became operational in September 1984.

Agreements with landowners on use of their land have been reached. An engineering consultancy company was hired to do planning of all construction work for the new array. The same company also assisted in the selection of contractors for the field work and also inspected performance and progress of all contractors on a regular basis.

The actual field work started in March 1984 with the deployment of the seismic vaults and drilling of two boreholes for seismometers. A central terminal building was completed in June. Trenching and cable laying started in June and was completed in August. All field work by contractors was finalized on August 15th, allowing Sandia representatives to start implementing the seismic system on August 1st, and continuing their work unimpeded until completion of system deployment early September.

The work related to transmission of data from the new array to various locations in the U.S. via satellite and to the NORSAR Data Processing Center at Kjeller, via a new 64 Kbits/s digital land line, progressed satisfactorily. Data reception at Sandia by satellite was accomplished

in late September 1984. The new land line for transmission of data to the NORSAR Data Processing Center was installed in September, and after some initial technical problems, continuous recording of NORESS data started at Kjeller on January 2, 1985.

An IBM 4341 Model K10 processor was purchased during the reporting period. This processor is used for on-line processing of the data from the new array. In addition, two Megamux multiplexing units and an IBM/XT computer were acquired. These are communication interfaces for data transmission via the land line in Norway and via the ARPANET for transmission of seismic event bulletins to the U.S., respectively.

Based on the recordings obtained to date, a preliminary evaluation of the event detection capability of the new array has been conducted. This evaluation indicates the following approximate detection thresholds for various ranges and source regions: Distance range 0-200 km: close to M_L = 0. Distance range 200-1500 km: increasing to M_L = 2-2.5 at 1500 km. Distance range 1500-3000 km: m_b = 2-3 for Eurasia. Distance range 3000-10000 km: m_b = 3 or slightly better for the test sites at Semipalatinsk (U.S.S.R.) and Lop Nor (China), between m_b 3 and 4 for Eurasia in general and between m_b 4 and 5 for the Western Hemisphere.

II. GENERAL BACKGROUND

The purpose of the development of an experimental regional array in Norway is to take advantage of the extremely good propagation of high-frequency energy for regional seismic phases in Eurasia. Since Norway is located within the same geologic plate boundary as the Soviet Union, the deployment of such an array in Norway will provide important new insight with respect to the projected performance of possible future in-country stations in the U.S.S.R.

The array has been constructed in Norway as a joint enterprise between Sandia National Laboratories, Albuquerque, U.S., and NORSAR, and initial data from the array were available from September 1984. Seismic data are being transmitted via satellite to several recipients in the U.S., and via a 64 Kbits/s digital land line to the NORSAR Data Processing Center at Kjeller.

Sandia's role in the joint undertaking has been the design and engineering of the electronics of the array system. Sandia representatives were present in Norway during the summer of 1984 for the field deployment and subsequent testing of seismometers, amplifiers, intra-array communication, central microprocessors, etc.

Over the past five years, NORSAR has conducted extensive field experiments to assess the potential of regional arrays in detection and location of regional seismic events. Results obtained from this work have been directly utilized in the planning and design work for the new array. The current and previous NORSAR research contracts with DARPA have contained several tasks that relate directly to the processing of data from regional arrays like the new NORESS array now implemented. In particular, a processing package (RONAPP) for on-line detection and location of regional seismic events has been developed and tested. The data from the new NORESS array are now being subjected to real-time processing using the RONAPP algorithm.

Under this contract, DARPA provided funds for the initial deployment of the new array. In addition, an IBM 4341 computer now being used for on-line analysis of data from the new array, has been purchased during the reporting period. This computer is the first item acquired for the new processing center at Kjeller. Additional items have been proposed for the FY85 contract.

NORSAR's involvement with the field deployment of the new array was related to the site preparation and installation. All construction work (trenching, acquisition and deployment of vaults, drilling of boreholes and the construction of a central terminal building in the array) was organized, supervised and administered by NORSAR, with the actual construction work being contracted to local construction companies. This report gives an account of the progress of the field work, and includes figures showing the essential elements being constructed (central station, vaults, boreholes and trenches).

Also included in the present report is a description of work related to the transmission of the seismic data via satellite to the U.S. and also via digital land line to the NORSAR Data Processing Center at Kjeller.

Finally, a preliminary evaluation of the event detection capability of the new array for various event distance ranges is given.

III. MISCELLANEOUS ACTIVITIES RELATED TO THE FIELD WORK

III.1 Land acquisition

The landowners affected by the new array were all approached during the fall of 1983. A lumbering company is the major landowner in the area. In addition to this company, three other landowners are affected, each of these having no more than one seismic vault and a trench less than a couple of hundred meters long on their land.

Contracts have been negotiated with all landowners and were signed in December 1983. The three minor landowners all accepted a nominal compensation (to be paid once) for the future inconvenience of having installations and trenched cables on their ground. With the major landowner a different agreement was reached. For an amount to be paid yearly, he has accepted to make sure that no new activities will be taken up within the array site that could produce local noise that could be potentially harmful to the seismic data. In addition, yearly amounts will be paid for use of roads in the area and for the inconvenience represented by the presence of the array.

III.2 Planning and inspection of construction work

Østlandskonsult A/S, an independent engineering consultancy company, was hired to work out the detailed plans for all site construction activities. All plans and specific descriptions were completed in January and tender documents were distributed to potential bidders following public announcements.

Østlandskonsult A/S assisted in the evaluation of bids and the selection of contractors for the various jobs, and by the end of March, all contracts were placed.

Østlandskonsult A/S was also contracted to do inspection and control of all field activities by the construction companies. This work has been done in close cooperation with NORSAR personnel.

III.3 Coordination meetings

During the reporting period, meetings have been held both in Norway and Albuquerque for coordination of the field work during the summer of 1984 and evaluation of the results from the initial array operation.

In January, during a meeting in Albuquerque, detailed information was exchanged to a level that permitted finalizing of all plans regarding the array construction work.

In March, representatives of COMSAT, Sandia and NORSAR met in Norway to discuss matters related to the satellite transmission of data to the U.S.

Another planning meeting took place in Albuquerque in early May. Apart from deployment work this summer, future operation of the array was discussed during this meeting.

Sandia representatives were present in Norway from late May till mid-September for the installation of the seismic system.

In early November Sandia and NORSAR representatives met in Albuquerque for the first evaluation of the performance of the new array.

III.4 Transportation

The first shipment from Sandia with about 60 tons of cables, terrain vehicles and antenna equipment arrived in Oslo on a commercial vessel on May 30th. NORSAR's handling agent cooperated with the U.S. Air Force Transportation Office in Oslo on customs clearance, and arranged transportation to the array site.

The second shipment (about 10 tons of equipment) arrived by direct flight from Albuquerque to Oslo on July 25th. Customs clearance and transportation were done as before.

IV. FIELD WORK

The geometry of the new array is shown in Fig. IV.1. The elements of the array are organized in four concentric rings around the center. The central element is a 3-component instrument in a 60 m deep borehole. The remaining 24 elements are deployments in shallow vaults (21 instruments recording vertical ground motion only, and 3 3-component systems). In addition, there is another 60 m deep borehole near the center of the array, housing a 3-component broad-band instrument. Data are transmitted within the array via buried cables to the central terminal building situated close to the central element in the array geometry. From this building the seismic data are transmitted via satellite to the U.S. and also via a land line to Kjeller.

IV.1 Trenching and cable laying

It took about 15 km worth of trenches to connect all sites in the array with the central terminal building. Approximately 28 km of fiber optic signal cables and 44 km of power cables (all supplied by Sandia) were placed in the trenches. The operations started with clearing of paths for the trenches during the winter of 1984. This work was done by the major landowner in the area. The contractor chosen for the trenching and cable laying operations started work in mid-June. The procedure chosen was to string out all cables along the trench path and then run the back-hoe over the path for the trench digging, followed by placing all cables in the trench and finally backfill gently (by hand for the lower 15 cm of overburden) to avoid damage to cables. This work proceeded generally in accordance with the planned progress and was completed on August 15th. Fig. IV.2 shows cross sections of various types of trenches.

IV.2 Boreholes

The array has two boreholes, one at the center point of the array geometry (Fig. IV.1) and the other about 5 m away from the first one. These holes are for a 3-component short-period instrument and

3-component broad-band instrument, respectively. Hole depths are 60 m with an inside casing diameter of 231.9 mm.

The holes were drilled in the spring of 1984. Acquisition of the tube casings and their actual deployment in the holes by injection of concrete grout between the tube casings and the hole walls was completed early July. Figs. IV.3 and IV.4 give details for the boreholes.

Hole-locks provided by Sandia were deployed in the holes. A hole-lock orientation survey was undertaken by the Stavanger, Norway, office of Sperry-Sun. This survey showed that the inclination of the two holes is 0.58 and 0.82 degrees, which in both cases is well within the requirement of 2.5 degrees.

IV.3 Element vaults

It was decided to use prefabricated bottomless fiber glass tanks for the shallow vaults in the array. In addition to being economically favorable (actual tank based on standard units from the manufacturer), this approach was believed to be the best solution to the problem of achieving absolutely waterproof vaults. It was clear at an early time that several vaults would have to be placed in locally flat and swampy places, which could have made it difficult to avoid water leakages for conventionally built concrete vaults.

A sketch drawing of a fiber glass tank is shown in Fig. IV.5. Twenty-four tanks were acquired during February and March and the deployment work started in March. After excavating the soil, a hole approximately 3 m deep was blasted and a concrete pad was prepared at the bottom. The tank was then placed in a circular channel on top of this pad and sealed using water proof epoxy cement. Backfilling was done carefully to prevent damage to the side walls of the tank. The work with the deployment of the shallow vaults was completed on July 1st. The solution adopted for the element vaults appears to be successful, and only one minor leakage was identified during the months following the

deployment. This leakage was easily stopped by additional injection of epoxy cement. The climate inside the vaults appears to be very stable and favorable; temperatures are close to 40°F, irrespective of the outside temperature.

IV.4 Central terminal building

Fig. IV.6 shows the central terminal building. The building is located 10 m away from the center of the array geometry. The contractor chosen for constructing the building completed it on June 15th after a two-month effort.

The larger room underground is for the central processor for acquisition, control and transmission of the data from the 36 seismometers in the array. The smaller room underground houses batteries, which need a separate, well-ventilated room due to hydrogen leakage.

The 4.5 m diameter satellite antenna is placed as shown in Fig. IV.6. It faces an INTELSAT satellite in position 213.54° from true north at an elevation of 16.8°. A hypolon cover, which is transparent to the radio frequency signals, constitutes the wall of the antenna building which faces the satellite. The ground in front of the building has been cleared for trees to provide free sight for the antenna.

IV.5 Summary of field work

All field work progressed according to scheduled plans or with minor delays. Some time margins were, however, built into the original progress schedule, in order to make sure that all work by the contractors would be completed by August 15, 1984. This allowed the Sandia representatives to start system implementation work on August 1st and to continue their work unimpeded until completion of system deployment.

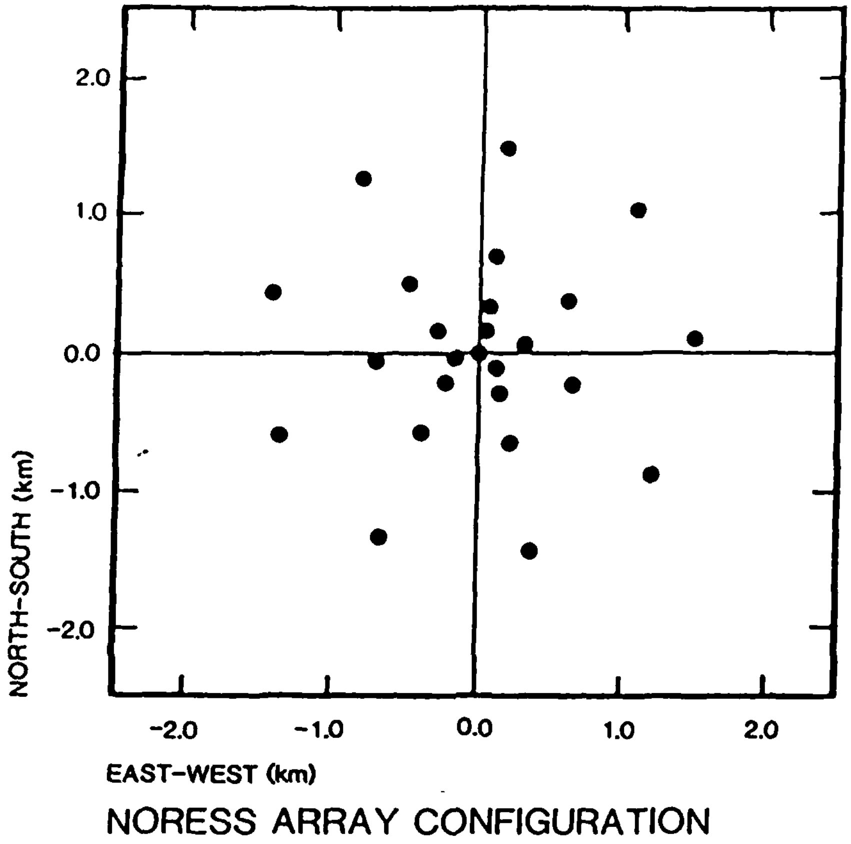

Fig. IV.1 Geometry of the new regional array NORESS in Norway. Each dot represents either a 3-axis or a single (vertical) axis instrument.

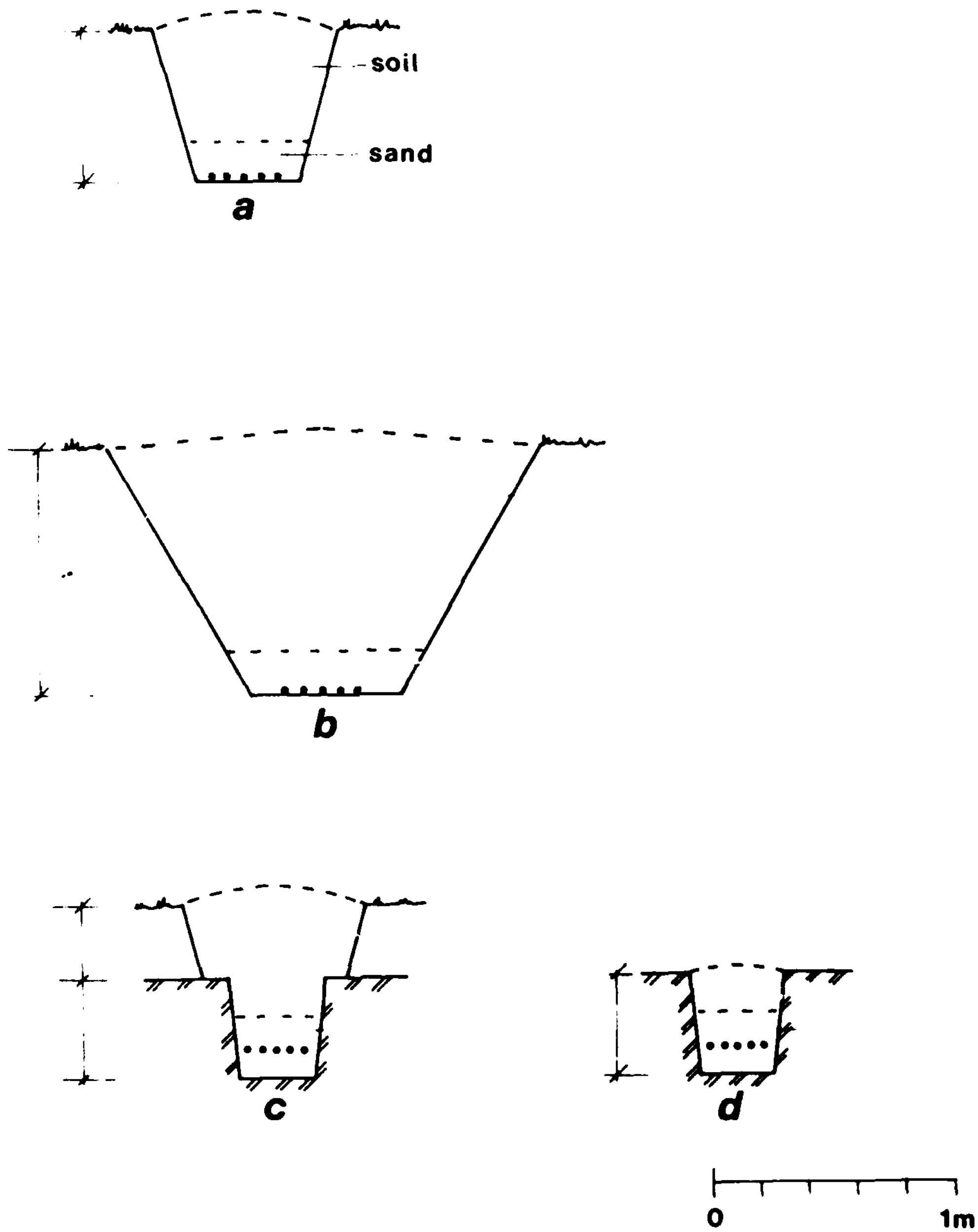

Fig. IV.2 Cross sections of various trench types, with cables in bottom. a) Standard trench in soil. b) Trench in swampy areas. c) Trench blasted in rock with soil overburden. d) Trench blasted in rock with no overburden.

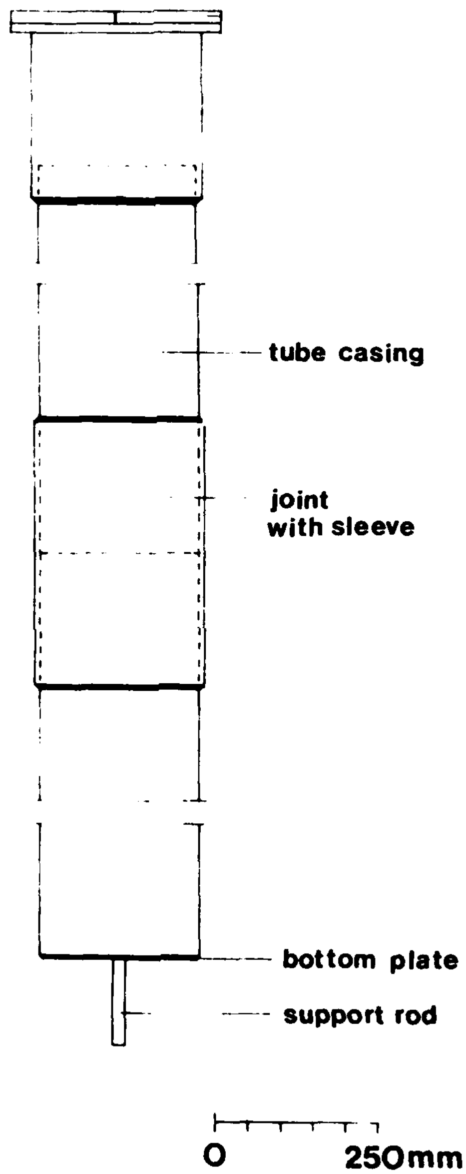

Fig. IV.3 Borehole casing with detail of joint. The 60 m long casing is composed of 10 tubes each 6 m long, welded together with an outside sleeve.

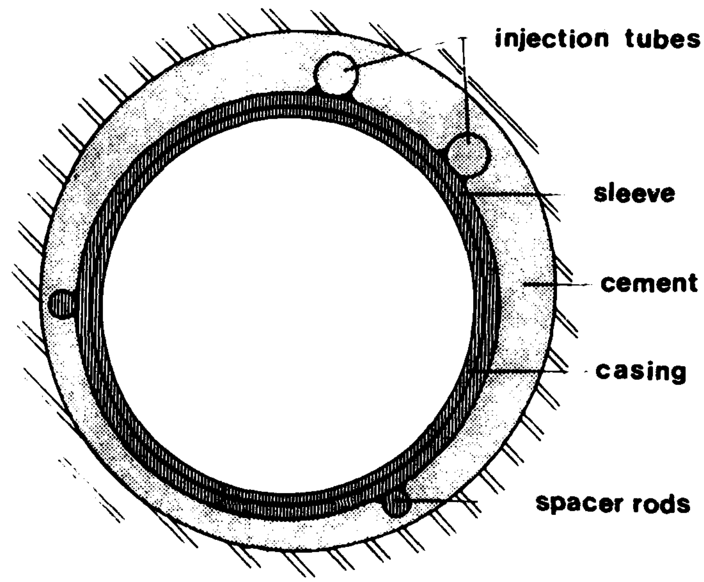

Fig. IV.4 Cross section of borehole with casing, sleeve, injection tubes (for pumping of cement), spacer rods and cement between the casing and the rock.

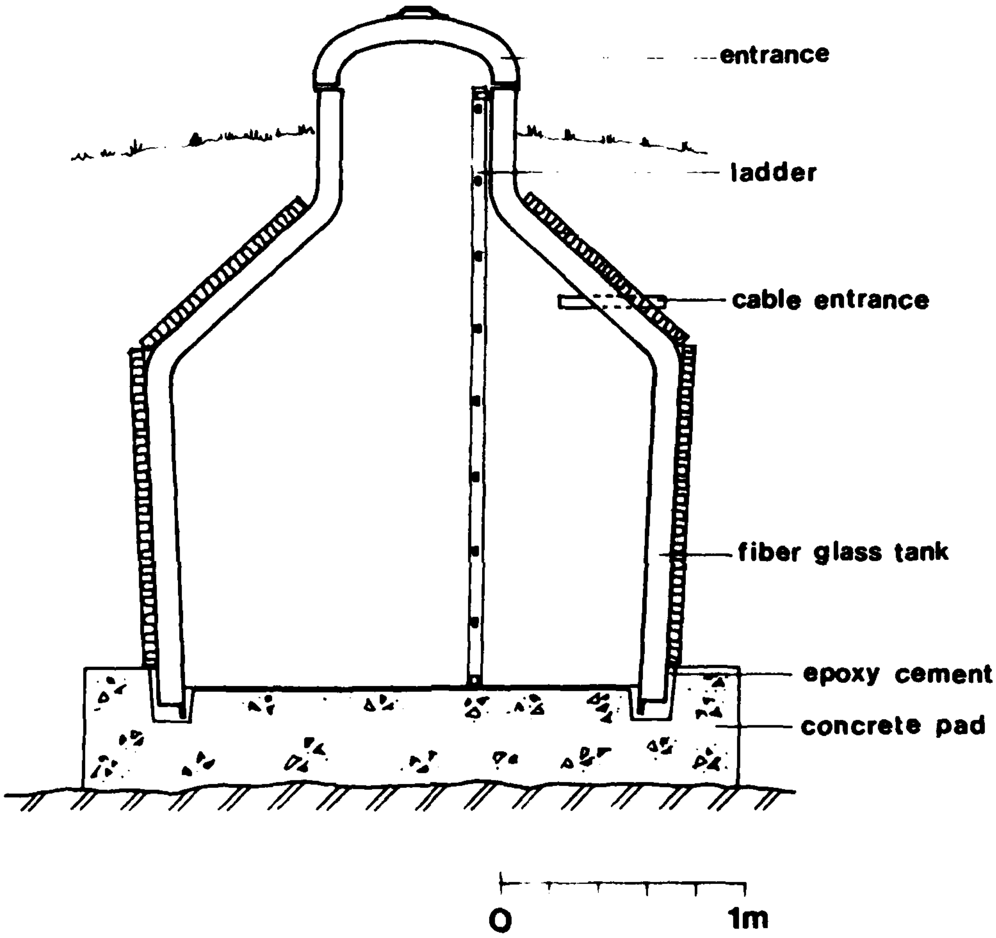

Fig. IV.5 Element vault for seismometer deployment.

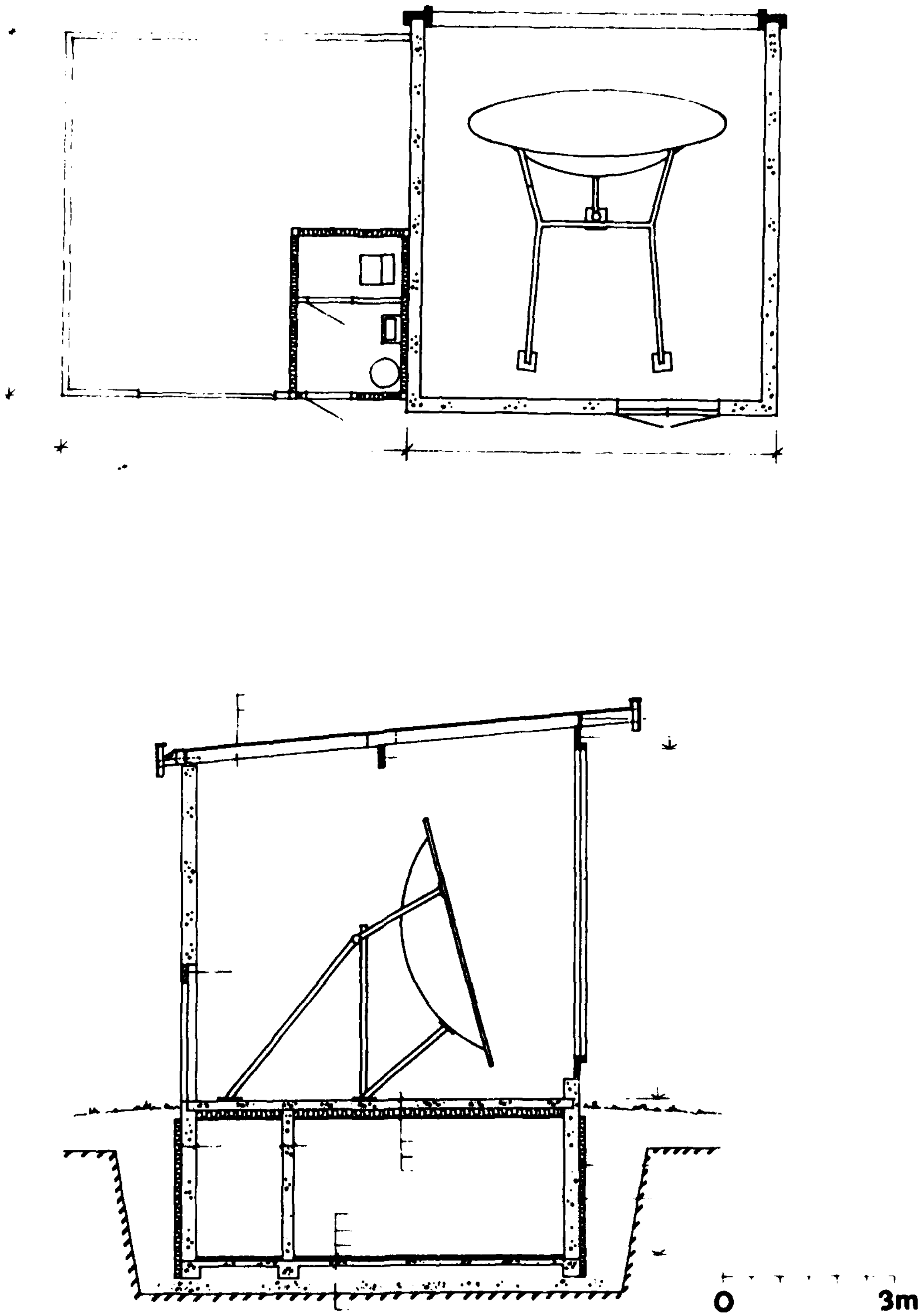

Fig. IV.6 The central terminal building. Top: Top view showing the antenna room and an adjacent storage room. Bottom: Cross section with underground rooms for electronic equipment and central processors.

V. DATA TRANSMISSION

V.1 Satellite transmission of data to the U.S.

During the reporting period, several meetings were arranged with the Norwegian Telecommunications Administration (NTA), with discussions on data transmission via satellite to the U.S. In January, NTA applied to INTELSAT for approval of a non-standard earth station for data transmission from the new array. The INTELSAT Board of Governors approved of such an earth station in March. By contract between COMSAT General and Sandia, COMSAT is to provide this satellite service from Norway to various locations in the U.S. In accordance with NTA's conditions (NTA being responsible towards INTELSAT for the operation of the earth station in Norway), the licence and provisional ownership of the antenna equipment located in Norway reside with NORSAR.

NTA has also allowed NORSAR to operate and maintain the antenna station and a contract between COMSAT and NORSAR on these matters has been negotiated. A dedicated telex line from NTA's control center in Oslo to the antenna site allows NTA to control remotely and on a 24-hours-a-day basis the transmitter high voltage supply.

The installation work for the equipment for satellite transmission of data progressed satisfactorily. The mechanical parts of the satellite antenna were mounted inside the central terminal building in late June, and all electronic parts were in place by late August. An extensive verification test sequence initiated late August proved that the performance of the NORESS earth station complies with the INTELSAT technical requirements for operation with INTELSAT satellites. Transmission of seismic data to the U.S. started late September and in a regular mode from November 1st.

V.2 Land line to Kjeller

The seismic data from the new array are transmitted to Kjeller via a new 64 Kbits/s digital land line. NTA's work with this line suffered from several delays due to technical problems. These problems have now been solved, and from January 2, 1985, data from NORESS have been

transmitted to Kjeller in a continuous mode. However, data from the period late September through December have been requested from Sandia, Albuquerque (one of the U.S. institutions receiving data from NORESS via the satellite link).

VI. EQUIPMENT PURCHASED

An IBM 4341 Model K10 processor has been purchased during the reporting period. This processor is the central unit in the on-line processing of data from the new array. A processing package for analysis of array data (Mykkeltveit and Bungum, 1984) has been implemented on this processor.

Two Megamux multiplexing units have been acquired. These are for the transmission of data from the field installation to the Data Center at Kjeller.

Finally, an IBM/XT computer has been purchased. This computer is used as an interface to the ARPANET, for transmission of seismic event bulletins to the Center for Seismic Studies, in Rosslyn, VA.

VII. THRESHOLD CAPABILITY OF THE NEW ARRAY FOR SMALL MAGNITUDE SEISMIC EVENTS

Based on the recordings obtained to date, a preliminary evaluation of the event detection capability of the new array has been conducted. A summary of the results are presented in this section. It should, however, be noted that a considerably larger recording and evaluation period is necessary in order to obtain more reliable threshold estimates, and such work will be carried out under subsequent contracts.

VII.1 Local and regional seismic events

The evaluation procedure has been to compare NORESS-detections to reportings by local seismological agencies in Scandinavia and Finland. A local magnitude scale developed at the University of Uppsala, Sweden, has been used in assessing the size of recorded events. Our preliminary results are as follows:

a) **Distance range 0-200 km**

At this range, NORESS records an abundance of very small events, almost none of which are reported by any other agency. The threshold at this range is probably close to $M_L = 0.0$. An example of recordings of a mining explosion ($M_L = 1.5$) at 120 km distance is shown in Fig. VII.1, and the processed NORESS results are displayed in Fig. VII.2. This small event produces very strong signals (both P and Lg), almost 2 magnitude units above the detection threshold.

b) **Distance range 200-1500 km**

In this range, P and Lg are often detected together for a recorded event. The treshold increases rapidly with distance, and the P-threshold is approximately $M_L = 2.0$-2.5 at 1500 km epicentral distance. It is worth noting that P is usually more high frequent than Lg, whereas Lg often have a larger signal amplitude. Nevertheless, P-detection appears to be most efficient, because of

the very steep decline in seismic noise level with increasing frequency.

c) **Distance range 1500 - 3000 km**

In this range, large regional variations in detectability are observed. In particular, the low signal frequency of events from the Mid-Atlantic ridge gives a high threshold, whereas detectability of events from Eurasia is much better. Lg is very seldom detected in this distance range. Estimated P-thresholds range from $m_b = 2$ to $m_b = 3$ for Eurasia.

VII.2 Teleseismic events

Distance range 3000 - 10000 km

In this "teleseismic" range, only P-detections are of significant interest in the short period band. Again, there are considerable regional variations in detectability. It is well known that signal "focusing" effects beneath the receiver are a significant factor in this regard, and any evaluation must therefore take this into consideration. The NORESS site is particularly good for certain areas of Central Asia, including the nuclear test sites at Semipalatinsk (U.S.S.R.) and Lop Nor (China). At these sites, a threshold of $m_b =$ 3.0 or slightly better has been determined. In other areas from which signals with rich high frequency contents are seen, such as the Kurile Islands and Hindu Kush, the threshold is between m_b 3 and 4. For signals from the Western Hemisphere, the high frequency content is very low, and the threshold is between $m_b = 4$ and 5.

An example of recordings from a presumed underground explosion at Semipalatinsk ($m_b = 4.3$) is shown in Fig. VII.3. Note the high signal-to-noise ratio on each individual array channel. The array beam has an SNR of close to 100, implying that a Semipalatinsk explosion of a size 1.5 m_b units smaller than the one displayed would probably have been detected.

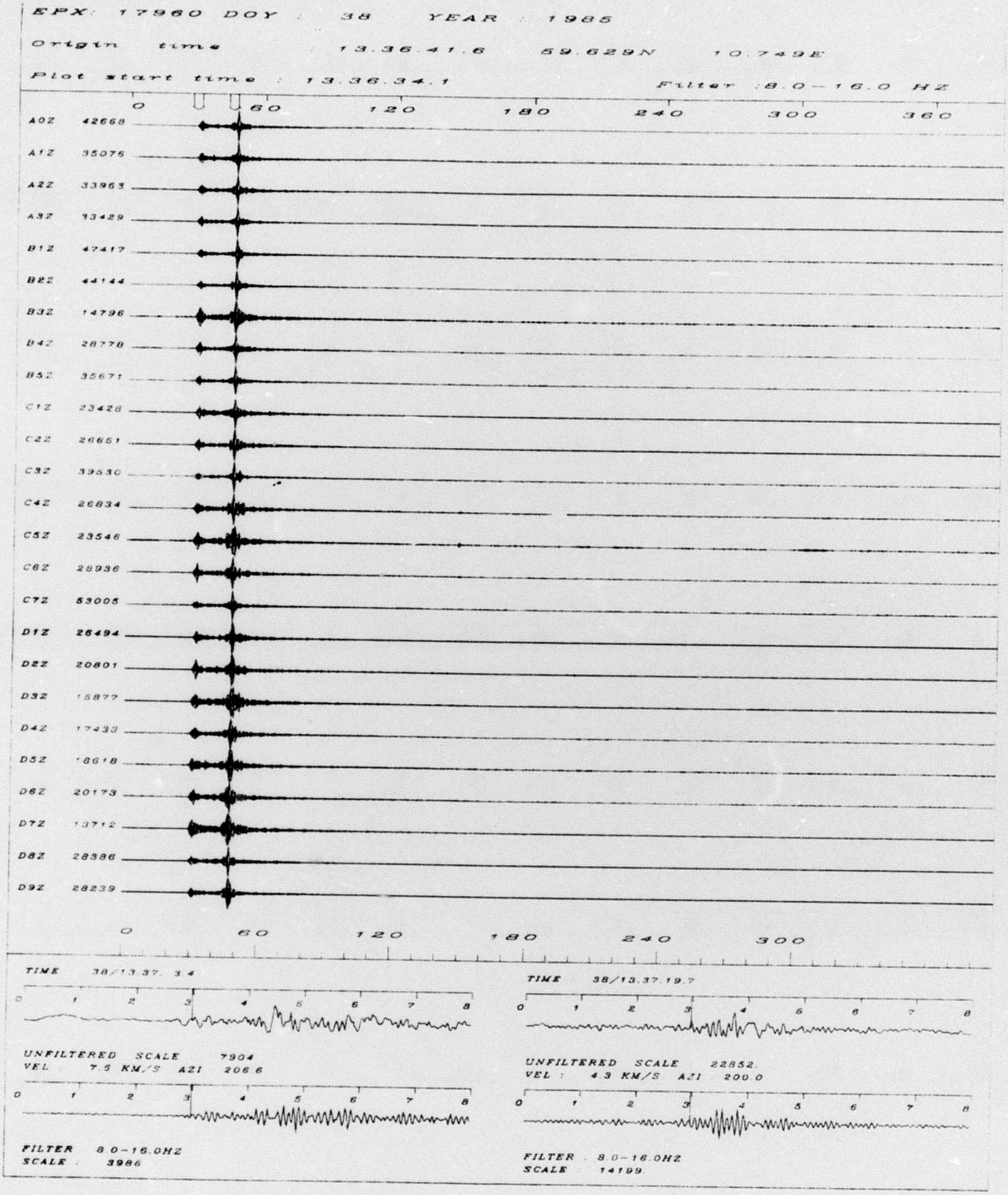

Fig. VII.1 NORESS recordings for a mining explosion (M_L =1.5) at a distance of 120 km. Top: Recordings for the 25 vertical instruments. Bottom: Beams (unfiltered and filtered) formed with velocity and azimuth as determined by the automatic signal processing following each detection (detection times indicated by broad arrows above uppermost trace).

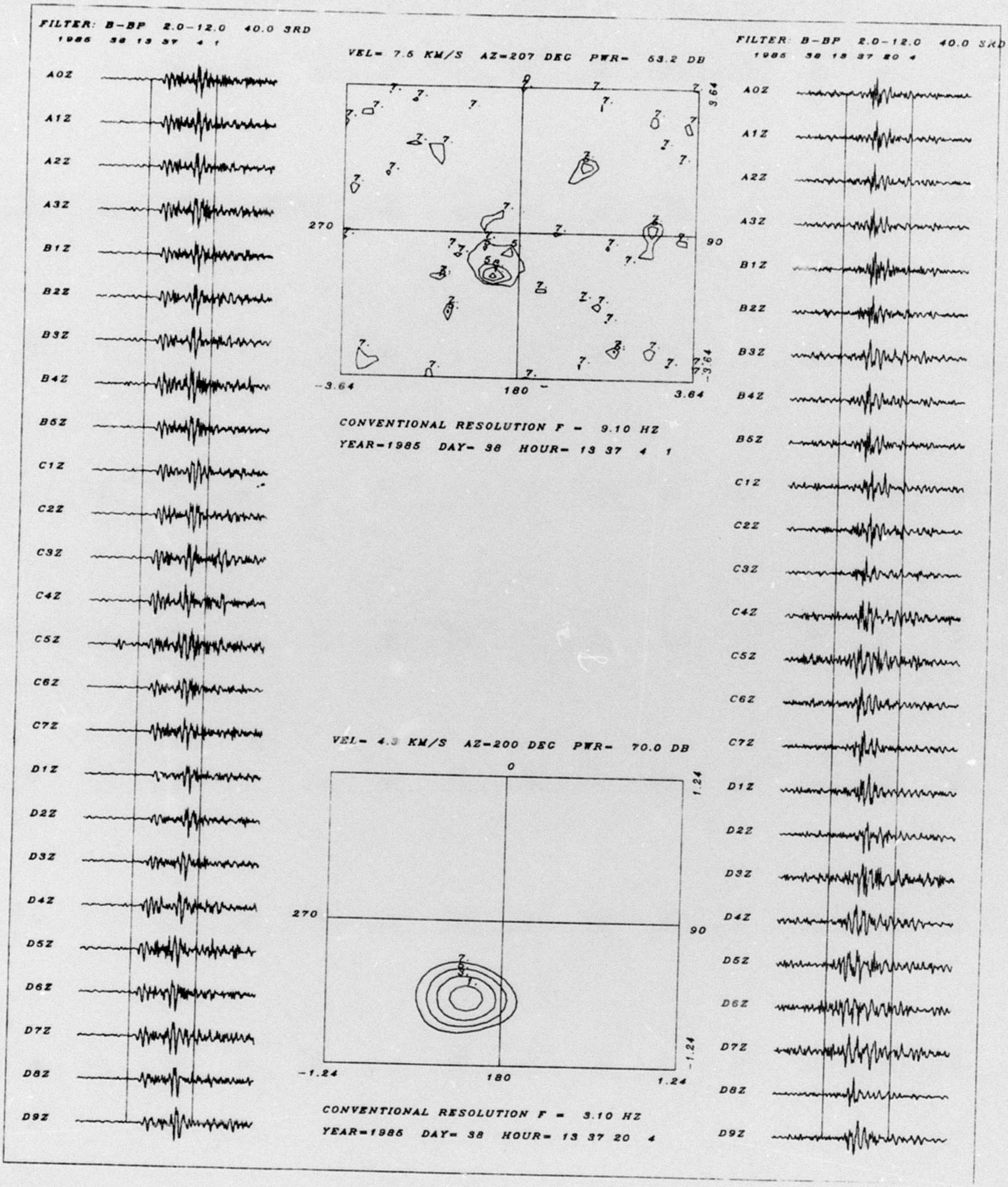

Fig. VII.2 Conventional frequency-wavenumber analysis for the P- and Lg-phases from the event shown in Fig. VII.1.

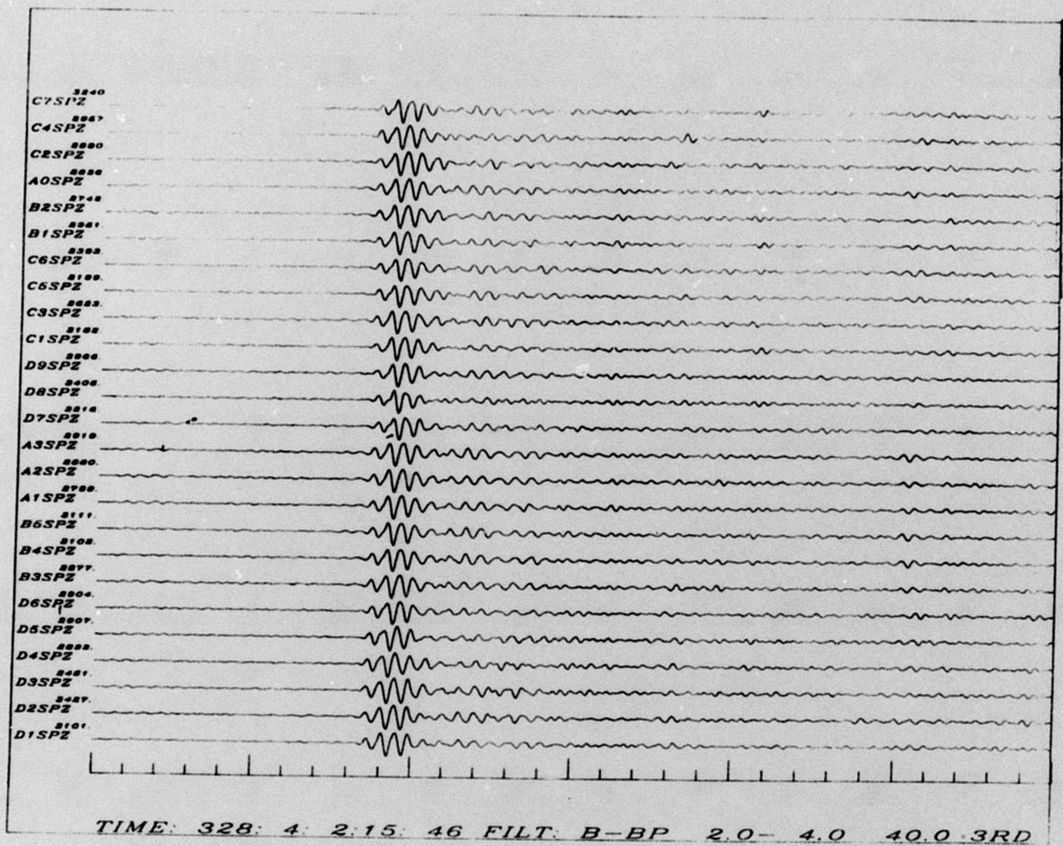

Fig. VII.3 NORESS recordings (25 vertical instruments) from a presumed underground Semipalatinsk explosion ($m_b = 4.3$). The time window covered is 30 sec long and all channels are filtered with a 2-4 Hz bandpass filter.

VIII. REFERENCES

Mykkeltveit, S. and H. Bungum (1984): Processing of regional seismic events using data from small-aperture arrays. Bull. Seism. Soc. Am., 74, 2313-2333.

UNCLASSIFIED
SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

1a. REPORT SECURITY CLASSIFICATION Unclassified	1b. RESTRICTIVE MARKINGS
2a. SECURITY CLASSIFICATION AUTHORITY	3. DISTRIBUTION/AVAILABILITY OF REPORT Approved for public release; Distribution unlimited
2b. DECLASSIFICATION/DOWNGRADING SCHEDULE	
4. PERFORMING ORGANIZATION REPORT NUMBER(S)	5. MONITORING ORGANIZATION REPORT NUMBER(S) AFOSR-TR- 85-0396
6a. NAME OF PERFORMING ORGANIZATION NORSAR / 6b. OFFICE SYMBOL (If applicable)	7a. NAME OF MONITORING ORGANIZATION AFOSR/NP
6c. ADDRESS (City, State and ZIP Code) Kjeller, Norway	7b. ADDRESS (City, State and ZIP Code) Buidling 410 Bolling AFB DC 20332-6448
8a. NAME OF FUNDING/SPONSORING ORGANIZATION AFOSR / 8b. OFFICE SYMBOL (If applicable) NP	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER F49620-84-C-0013
8c. ADDRESS (City, State and ZIP Code) Buidling 410 Bolling AFB DC 20332-6448	10. SOURCE OF FUNDING NOS. PROGRAM ELEMENT NO.: 62714E PROJECT NO.: 4950 TASK NO.: 00 WORK UNIT NO.:
11. TITLE (Include Security Classification) DEPLOYMENT OF A REGIONAL ARRAY IN NORWAY	

12. PERSONAL AUTHOR(S)
Dr Svein Mykkeltveit

13a. TYPE OF REPORT	13b. TIME COVERED	14. DATE OF REPORT (Yr., Mo., Day)	15. PAGE COUNT
FINAL	FROM ~~1 Dec 83~~ TO ~~30 Nov~~ 84	30 Jan 85	26

16. SUPPLEMENTARY NOTATION

17. COSATI CODES			18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
FIELD	GROUP	SUB. GR.	

19. ABSTRACT (Continue on reverse if necessary and identify by block number) The purpose of the development of an experimental regional array in Norway is to take advantage of the extremely good propagation of high-grequency energy for regional seismic phases in Eurasia. The actual field work has been started with the deployment of the seismic vaults and feilling of two boreholes for seismometers. A central terminal building was completed. Trenching and cable laying was completed. Aff field work by contractors was finalized, allowing Sandis representatives to start implementin g the seismic system until completion of system deployment. The work related to transmission of data from the new array to various locations in the US via satellite and to the NORSAR Data Processing Center at Kjeller progressed satisfactorily. Data reception at Sandia by satellite was accomplished. The new land line for transmission of data to the NORSAR Data Processing Center was installed and continuous recording of NORESS data was started at Kjeller.

20. DISTRIBUTION/AVAILABILITY OF ABSTRACT UNCLASSIFIED/UNLIMITED ☒ SAME AS RPT. ☐ DTIC USERS ☐	21. ABSTRACT SECURITY CLASSIFICATION Unclassified
22a. NAME OF RESPONSIBLE INDIVIDUAL Dr Henry R. Radoski	22b. TELEPHONE NUMBER (Include Area Code) 202/767-4906 / 22c. OFFICE SYMBOL NP

DD FORM 1473, 83 APR EDITION OF 1 JAN 73 IS OBSOLETE.

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SECURITY CLASSIFICATION OF THIS PAGE